Serial No.: 09/810,653

Filing Date: 15 March 2001

Inventor: Shane J. Strutz

NOTICE

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ASSOCIATE COUNSEL (PATENTS)
CODE 1008.2
NAVAL RESEARCH LABORATORY
WASHINGTON DC 20375

PATENT APPLICATION/TECHNICAL DIGEST PUBLICATION RELEASE REQUEST

FROM: Associate Counsel (Patents) (1008.2)
TO: Associate Counsel (Patents) (1008.2)**EJECT DOWN-CONVERTER**." Request for release for publication.

REF: (a) NRL Instruction 5510.40C
(b) Chapter 6, ONRINST 5870.1C

Via: (1) Shane J. Strutz Code 5650)
(2) Division Superintendent (Code 5600)
(3) Head, Classification Management & Control (Code 1221)

SUBJ: Patent Application/Technical Digest entitled: **"ALL OPTICAL IMAGE R**

ENCL: (1) Copy of Patent Application/Technical Digest

1. In accordance with the provision of references (a) and (b), it is hereby requested that the subject Patent Application/Technical Digest be released for publication.

2. It is intended to offer this Patent Application/Technical Digest to the National Technical Information Service, for publication.

3. This request is in connection with Navy Case No. 82,914

JOHN J. KARASEK

3/20/07 (date)

Associate Counsel (Patents)

FIRST ENDORSEMENT Date:

FROM: Shane J. Strutz Code 5650)
TO: Division Superintendent (Code 5600)

1. It is the opinion of the Inventor(s) that the subject Patent Application/Technical Digest ~~(is)~~ (is not) classified and there is no objection to public release.

Inventor's Signature

SECOND ENDORSEMENT Date: 26 March 2001

FROM: Division Superintendent (Code 5600)
TO: Classification Management & Control (Code 1221)

1. Release of Patent Application/Technical Digest (is) (~~is not~~) approved.

2. To the best knowledge of this Division, the subject matter of this Patent Application/Technical Digest (~~has~~) (has not) been classified.

3. This recommendation takes into account military security, sponsor requirements and other administration considerations and there in no objection to public release.

Division Superintendent
Dr. Thomas G. Giallorenzi
Code 5600-Optical Sciences Division

THIRD ENDORSEMENT Date:

FROM: Head, Classification & Control (Code 1221)
TO: Associate Counsel (Patents) (1008.2)

1. This Patent Application/Technical Digest is authorized for public release.

Head, Classification, Management & Control

Inventors: Strutz et al.
Serial No.

PATENT APPLICATION
Navy Case No. 82,914

ALL OPTICAL IMAGE REJECT DOWN-CONVERTER

FIELD OF THE INVENTION

This invention relates to an optical down-converter for the mapping of received radio frequencies into an arbitrary intermediate frequency range while precluding interference between the received signals. More particularly, the invention relates to a device for improving image rejection to improve the harmonic spurs limiting system performance.

BACKGROUND OF THE INVENTION

Prior art image rejection systems providing significant frequency translation include those that use a digital phase modulator to produce a serrodyne phase modulated waveform, and those that split a received signal into two parts and then recombine them in such a way as to eliminate the unwanted image and carrier frequencies. Optical image rejection mixers that utilize the serrodyne method of frequency translation apply a sawtooth waveform to phase modulate the optical signal, thereby causing the optical frequency to shift. The achievable image rejection is limited by the number of discrete bits that can be implemented by the digital phase modulator when approximating the sawtooth waveform. This limits the image rejection to approximately 25 dB.

In the case of microwave image rejection mixers, the achievable image rejection is limited by the need for near perfect amplitude and phase control. As shown in **Figure 1**, a received radio frequency (RF) signal **124** is first divided into two signals **116** and **118** in a in-phase power divider **122**, mixed in associated mixers **112** and **114** with a local oscillator input **102** (LO IN) and split into associated signals **106** and **108** that are shifted 90°in a first 3 dB 90° hybrid power divider **123**. The output of the mixers **112** and **114** are then recombined with a 90° phase shift between the two components in a second 3 dB 90° hybrid power divider **126** and output as an intermediate frequency band **134**. Exact amplitude and phase matching with broad band signals is nearly impossible with strictly microwave components since the frequency response of each component varies. A typical device, with a 3° phase error and a 0.25 dB amplitude imbalance upon recombination, is limited to about 36 dB of image and carrier rejection. Further details on serrodyne frequency shifting can be found in Johnson et al., SERRODYNE OPTICAL FREQUENCY TRANSLATION WITH HIGH SIDEBAND SUPPRESSION, J. of Lightwave Tech., Vol. 6, No. 6, pg. 109, 1988.

Another optical image rejection down-converter described in U.S. Patent Application Serial No. 09/620,324 by Ward et al., entitled IMAGE REJECTING MICROWAVE PHOTONIC DOWNCONVERTER, Navy Case No. 79,800, filed July 17, 2000, employs an electronic mixer for up-converting signals into the passband of a bandpass filter followed by optical down-converting of the filtered signals into a desired output band, as shown in **Figure 2**, thereby providing greater than 60 dB of image rejection. The device allows telecommunications systems to down-convert the lower sideband of densely multiplexed ultra-wideband bandwidth channels into low frequency bands where conventional electronics can perform signal processing functions; has the image rejection (> 60 dB) to provide unambiguous signals for direction finding applications; and exhibits efficient image rejection that should permit multi-octave microwave frequency reception and compression. In addition, that invention is intrinsically remoteable, due to the various optical and electrical components that may be used to construct the subject device. The device, however, utilizes a first local oscillator at frequencies below the original frequency of a bandpass filter that may allow harmonics from the local oscillator to convert undesired input radio frequency (RF) frequencies into spurious signals presenting the output intermediate frequency band being applied to user electronics. These harmonics can be handled by the user electronics but additional signal processing would be required.

A recently developed all-optical image rejection system down-converter capable of removing the harmonics before entering the user electronics is described in U.S. Patent Application Serial No. 09/635,985 by Strutz et al., entitled ALL OPTICAL IMAGE REJECT DOWN CONVERTER, Navy Case No. 82,339, filed August 9, 2000. The device, which by eliminating the microwave mixers of the non-all optical prior art systems provides advantages over the prior art devices, is shown in Figure 3. Light from a fiber coupled laser, e.g. at a wavelength of approximately 1550 nm, is amplified and then divided into two paths by a polarization maintaining coupler. In one path, light is amplitude modulated by optical modulator MZM1 driven by a local oscillator LO1. The amplitude modulation causes light to be shifted from the fundamental beam into the RF sidebands. The second path includes two cascaded optical modulators, MZM2 and MZM3, where MZM2 modulates the light at a first frequency, e.g. 18 Ghz, after which the light is amplified by an erbium doped fiber amplifier and then modulated a second time by MZM3 driven by RF In, producing wavelengths at an input fundamental frequency, e.g. 1550 nm, a first modulated fundamental frequency, e.g. ± 18 Ghz, a fundamental ± RF In, and a second modulated fundamental frequency, e.g. ± 18 Ghz ± RF In. The light is amplified again before passing through a filter that selects one of the optical sidebands; optionally, the amplified light may be passed through multiple optical filters (not shown). Upon recombining the two paths, the beat signal produced by heterodyning the light at the filtered signal with the sideband produced by LO1 is detected and an intermediate frequency (IF) output is applied to an optical transmission line and then sent to user electronics (not shown). Although the system is advantageous for remote applications since it is composed of two fiber optic links, there may exist some inherent conversion loss ("CL"), e.g. on the order of up to about 60 dB, that may be undesirable in some applications. A preamplifier may then be necessitated to compensate for the CL, increasing the system's cost and complexity, and the system might also exhibit a limited spur free dynamic range.

SUMMARY OF THE INVENTION

The object of this invention is to is to provide an apparatus for the improvement of image rejection in image rejection mixing systems while removing harmonic spurs.

Another object of this invention is to provide a device having sufficiently large image rejection capability so as to allow precise determination of frequency for direction finding applications.

These and other objectives are accomplished by the all-optical image reject down converter which maps received radio frequency (RF) into an arbitrary intermediate frequency (IF) range, while precluding interference between the received signals. The invention converts a received radio frequency signal into an arbitrary intermediate frequency for use by an electronic circuit in other devices. An example of the system's ability to convert a received 9 GHz signal into a 2 GHz intermediate frequency is as follows. Optical light originating from a laser is divided into two paths. Light in a first path is transferred into an optical sideband by a first optical modulator or phase modulator (LO1 = 7 GHz). Light in a second path is converted into 9 GHz sidebands by a second, single (i.e., non-cascaded) optical modulator, generating light with an optical spectrum that includes many wavelengths. The light from the second optical modulator is then passed through a narrow, tunable optical filter that selects the 9 Ghz sideband, thereby producing an optical spectrum that primarily includes light at a frequency equal to the initial input laser frequency plus the 9 GHz signal. The filtered second path sideband is then heterodyned with the light from the first path, resulting in a down-conversion to 2 Ghz.

The use of a narrow-band optical filter allows the system to select a particular sideband for use in the heterodyne down-conversion. As a result, image frequencies present at the RF input are filtered out and are rejected. The image rejection of the system is a function of filter extinction.

The down-convertor allows telecommunications systems to down-convert densely multiplexed ultra-wide bandwidth channels into low frequency bands where conventional electronics can perform signal processing functions. It provides image reduction to provide unambiguous signals for applications such as direction finding. It exhibits a bandwidth sufficient for permitting multi-octave microwave frequency reception and compression. It has at least an order of magnitude reduction in conversion loss compared to other down-converters. The all optical down-converter is intrinsically remotable and therefore suitable for use in numerous fiber optic and antenna systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic diagram of a prior art electronic image reject system.

Figure 2 shows a schematic diagram of a prior art hybrid optical fiber/electronic image rejection down-converter.

Figure 3 shows a schematic diagram of a prior art all-optical image reject down-converter.

Figure 4 shows a schematic diagram of a single channel optical image reject down converter according to the invention.

Figure 5a shows a schematic of light originating from a laser transferred into an optical sideband by a Mach-Zehnder modulator.

Figure 5b shows a light signal that, after being amplified and modulated with additional sidebands generated by a received 9 GHz signal, has then been filtered to select the 9 Ghz sideband.

Figure 5c shows a filtered sideband heterodyned with a 7 GHz signal resulting in down-conversion to 2 Ghz.

Figure 5d shows a radio frequency (RF) input at 5 GHz mixed with a 7 GHz sideband from a local oscillator to produce a 2 GHz sideband which is rejected by the optical filter.

Figure 6 shows a schematic diagram of a multichannel optical image reject down-converter according to the invention.

Figure 7 shows a schematic diagram of a two channel optical image reject down-converter according to the invention.

Figure 8 shows a plot of conversion loss versus image signal powers with a RF input power of + 20 dBm.

Figure 9 shows a schematic diagram of a down-converter as in **Figure 8** in which the WDMs are replaced with PM couplers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to **Figures 4** through **5d**, a single channel down-converter **10** includes a fiber-coupled laser light source **12** producing an optical light signal **14** at an initial frequency, e.g. about 1550 nm. The light source **12** may be of any type that can be used to down-convert radio frequency (RF) frequencies through optical heterodyning. Light signal **14** is divided into a first path **16** and a second path **18** by a first 3dB polarization maintaining (PM) optical coupler **20**. In first path **16**, light signal **14** is modulated by a first phase modulator **22** driven with a first local oscillator (LO1) **24** operating at a frequency of approximately 2-26 Ghz. Virtually, any frequency band > may be chosen so long as the proper combinations of oscillator **24** and RF frequencies input into a second path modulator **30** (described below) are used. The modulation causes light to be shifted from the initial light signal **14** frequency into an RF sideband **26** (LO1=7 Ghz) as shown in **Figure 5a**.

In second path **18**, input laser light signal **14** is amplified by an amplifier **28** and then phase modulated by a second phase modulator **30** driven with an applied RF signal **32**, generating a light signal **34** having an optical spectrum that includes 9 Ghz sidebands and many optical wavelengths. Next, light signal **34** is passed through a narrow-band tunable optical filter **36** that is tuned to select a 9 GHz sideband **38** as shown in **Figure 5b**, producing a light signal **40** ideally having an optical spectrum at a frequency of the initial laser light signal **14** frequency plus 9 GHz sideband **38**. Optionally, instead of a single optical filter **34**, multiple optical filters may be used. Light signal **40** is then combined in coupler **46** with 7 GHz signal **26** from first path **16**, resulting in down-conversion to a 2 GHz signal **48** when signals **40** and **26** are mixed in a photodector **49**, e.g. a photodiode. Intermediate frequency output signal **48** is then applied to an optical transmission line for application to user electronics (not shown) at a remote location.

Narrow-band optical filter **36** allows selection of a particular sideband for implementing the heterodyne down-conversion, resulting in the rejection of unwanted image frequencies present at RF In **32**. For example, as shown in **Figure 5d**, absent filter **36**, an RF input **42** of 5 GHz mixing with 7 GHz sideband **26** would generate an undesirable duplicate 2 GHz signal **44** by forming an additional image at the system output. The image rejection capability of the system is accordingly a function of filter **36** extinction. As shown in **Figure 8**, improved down-converter **10** produces a 30 dB conversion loss (CL), providing a substantial improvement over the CL of the all optical down-convertor shown in **Figure 3** that can run as high as 60 dB. Furthermore, down-convertor **10** in requiring one less modulator and much less optical amplification has significantly decreased cost and complexity compared with prior art devices.

Optical modulators **22** and **30** and those described elsewhere herein are preferably Mach-Zehnder type optical modulators or phase modulators, however, it is well known to those skilled in the art that other types of optical modulators capable of generating optical sidebands may be utilized. Optical amplifier **28** and the other amplifiers described below are preferably Erbium doped fiber amplifiers (EDFA), however, it is recognized by those skilled in the art that other types on amplifiers may be utilized as long as they are capable of maintaining the polarization of light. Amplifier **28** and the other amplifiers described herein are optional and may be omitted depending on the performance required. PM fiber is preferred up to coupler **46**, although alternatively single mode fiber and polarization controllers may be used.

A significant advantage of the down-converter of the invention is its capability for building up many channels. Referring now to **Figure 6**, a multi-channelizer down-converter **200** includes a plurality of laser light sources **212**, each source **212** emitting a light signal **214** divided into a first path **216** and a second path **218** by an optical coupler **220**, in the manner as described above for down-converter **10** but involving multiple channels, whereby each light signal **214** is respectively modulated by a phase modulator **222** driven with a local oscillator (LO1-LO4) **224**.

In second path **218**, each light signal **214** is combined into a single fiber light signal **224** by a first WDM multiplexer **226** or other suitable device. Light signal **224** is then amplified by an amplifier **228** and phase modulated by a single (i.e., non-cascaded) modulator **230** driven with an RF signal **232**, generating a light signal **234** at the frequencies of the received signals. Light signal **234** is next passed through a single optical filter **236** positioned before a second WDM **238**, or optionally first through WDM **238** and then through multiple optical filters **236** (not shown), to select the desired RF sidebands of each individual laser wavelength. The laser wavelengths are each then recombined via couplers **240** in the manner described above with each beat signal **242** thereby generated by a photodetector **244** exhibiting the desired down-conversion of each received RF signal **232**. Again , the optical filter or filters 236 provide the image rejection. Path **218** is shared by each laser wavelength, allowing simultaneous down-conversion of the entire received bandwidth. Down-converter **200** advantageously utilizes WDM technology and enables many of the optical components to be utilized by every channel, decreasing the overall cost and providing a compact design.

A down-converter **300** as shown in **Figure 7** was built and tested. Light at a frequency of 1550 nm from a pair of fiber coupled lasers **302** was respectively divided into first paths **304** and

306 and into second paths **308** and **310** by a pair of 3 dB polarization maintaining couplers **312**. In paths **304** and **306**, phase modulators **312** and **314** respectively driven by LO1 and LO2 at 6-16 Ghz produced light shifted from the fundamental beam into the RF sidebands. In paths **308** and 310, the light was combined via 50/50 coupler 316, amplified by amplifier **318**, and then phase modulated by modulator **320** at the received RF In frequencies of 8-18 Ghz. The individual wavelengths were separated by a WDM **322** and the RF sidebands selected with optical filters **324** and **326** (3 dB bandwidth=0.6 Ghz). The selected sidebands were then respectively recombined with the light from paths **304** and **306** in couplers **328** and **330** and the beat signal between the sidebands was generated and detected by photodiodes **332** and **334**. Each channel enabled 0.5 Ghz of received bandwidth to be down-converted. This bandwidth may be increased with the use of wider bandwidth optical filters. The frequencies of LO1 and LO2 combined with the wavelength centers of the optical filters provided the desired 2-2.5 Ghz IF output frequency band. The RF power of LO1 and LO2 were fixed at 1 watt. As shown in **Figure 9**, the WDM may be replaced with a 3 dB coupler **329**, and the lasers are tuned to wavelengths passed by the optical filter.

Down-converter **300** is ideal for remote applications since it is composed of fiber optic links. It can be used to down-convert microwave signals from low frequencies (< 2 Ghz) to as high as 50 Ghz given current technology, and its capability should extend to and exceed 100 Ghz based on projected future technology.

The invention described herein is an improved all optical image rejection system, providing more than 20 dB of image rejection while maintaining less than about 30 dB of conversion loss. Ultrawideband microwave frequency bands may be mapped into narrow frequency bands to simplify processing and the large image rejection capability of this invention allows the precise determination of frequency for direction finding applications. The invention allows provides a method of shifting frequency for radar applications.

Although the invention has been described in relation to an exemplary embodiment thereof, it will be understood by those skilled in the art that still other variations and modifications can be affected in the preferred embodiment without detracting from the scope of the invention as described in the claims.

ABSTRACT OF THE INVENTION

An optical image reject down-converter for mapping a received radio frequency (RF) into an arbitrary intermediate frequency range and for precluding interference between the received signals. A received radio frequency signal is down-converted into an intermediate frequency band for use by an electronic circuit in other devices. Optical light is divided into a first path and a second path. Light in the first path is transferred into an optical sideband by a first optical modulator or phase modulator. Light in a second path is converted into sidebands by a second, non-cascaded optical modulator and then passed through a tunable narrow-band optical filter which selects the desired sideband. The optical spectrum of the second path then primarily includes light at the frequency equal to the original laser frequency plus the additional sidebands. The filtered sideband is heterodyned with the light from the first path, resulting in a down-conversion to the desired intermediate frequency. Image frequencies initially present in the optical link are thereby filtered and rejected.

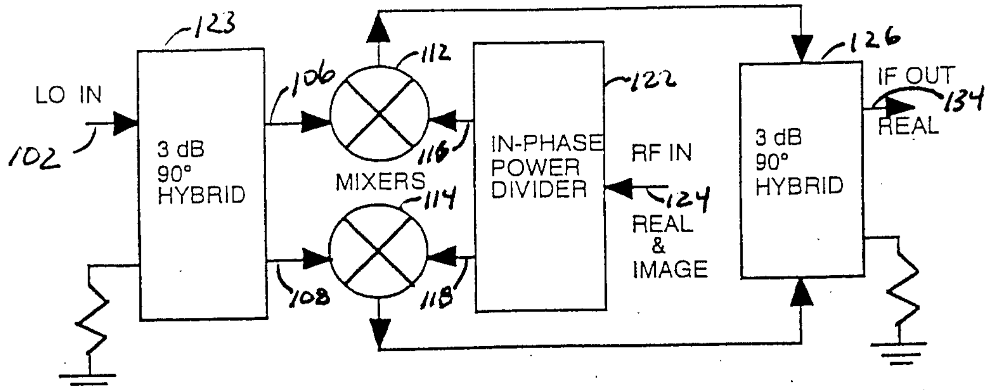

Figure 1 Prior Art; Electronic Image Reject Configuration.

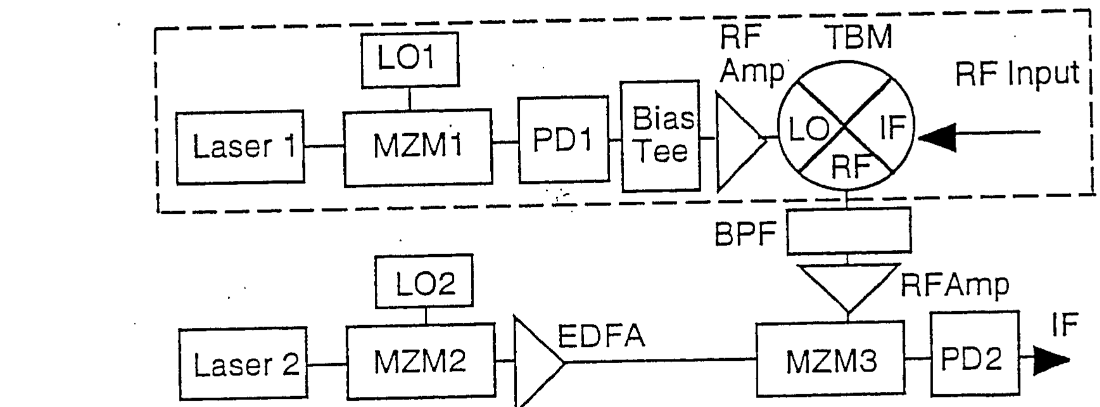

Figure 2 Prior Art; Hybrid Optical Fiber / Electronic Image Rejection Downconverter.

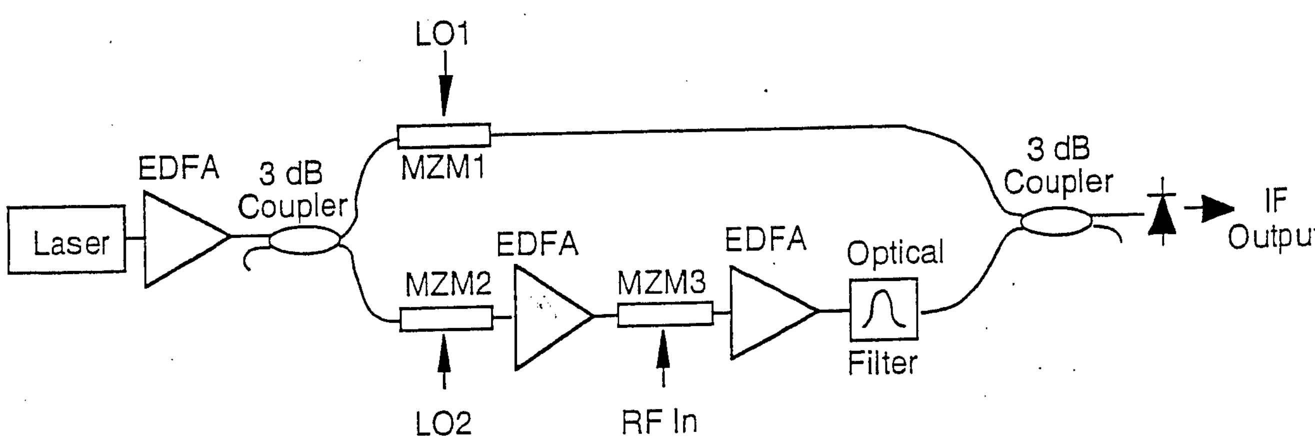

Figure 3 Prior Art-All Optical Image Rejection Downconverter

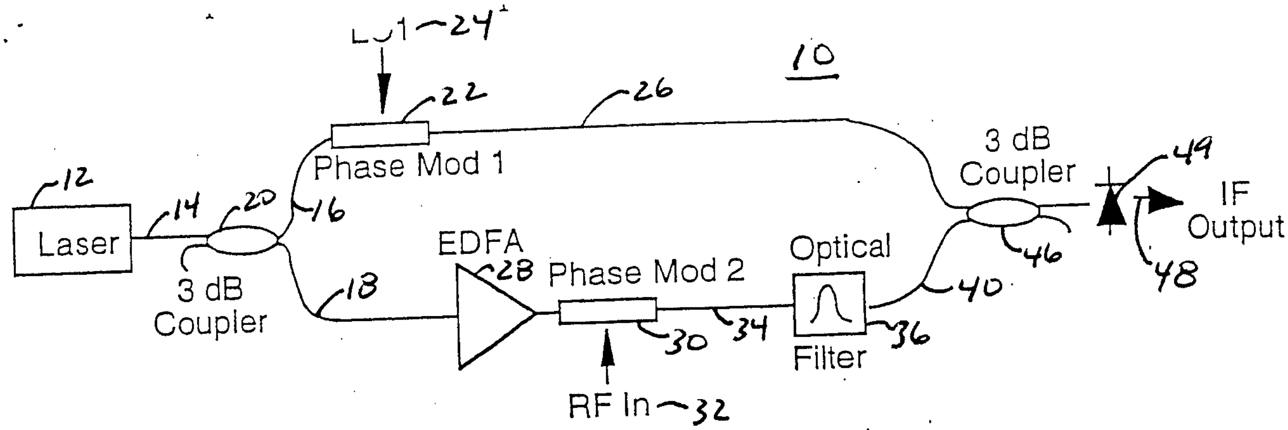

Figure 4

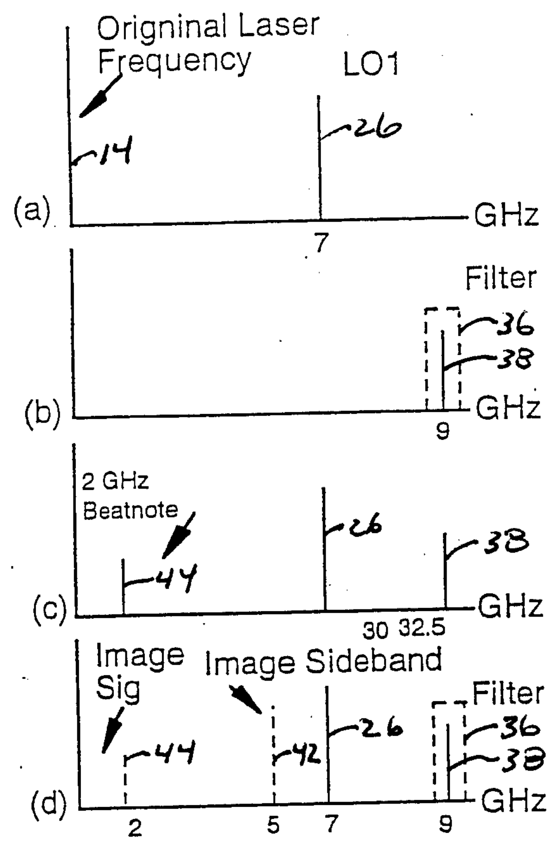

Figure 5

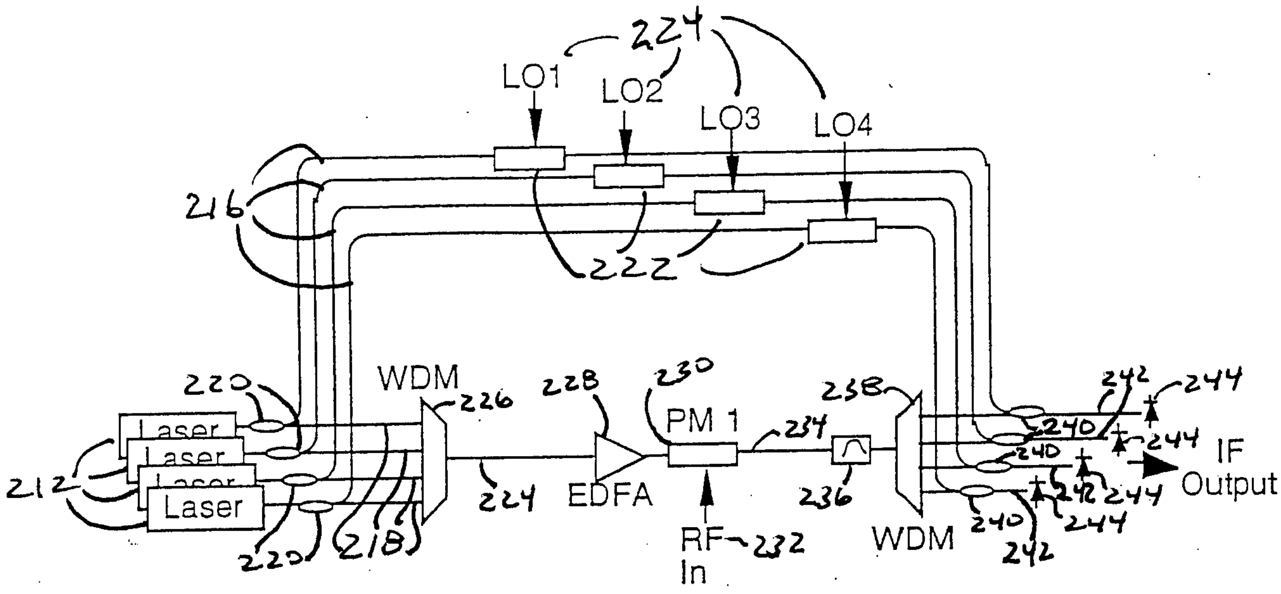

Figure 6

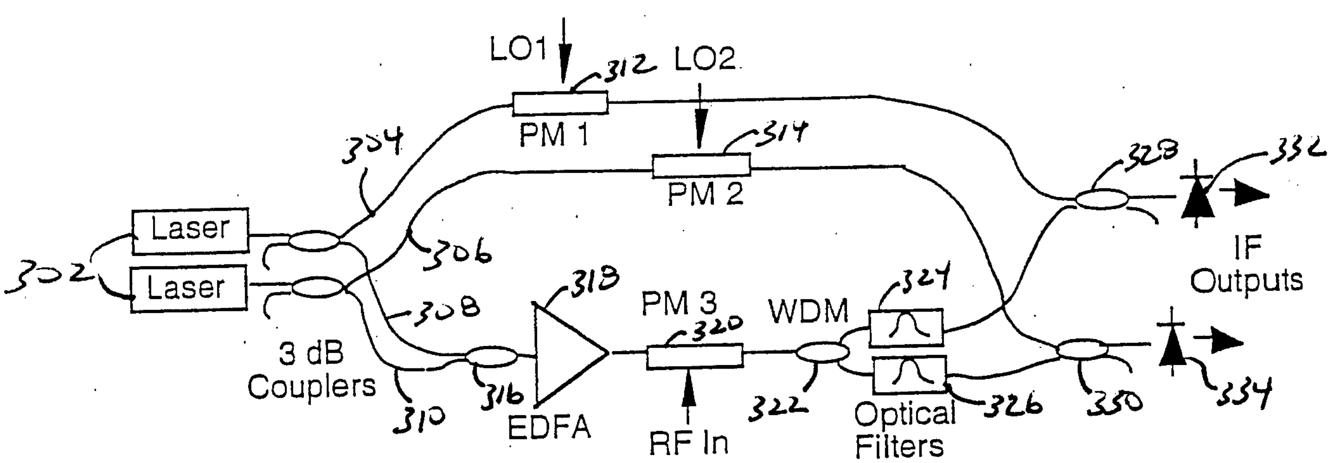

Figure 7

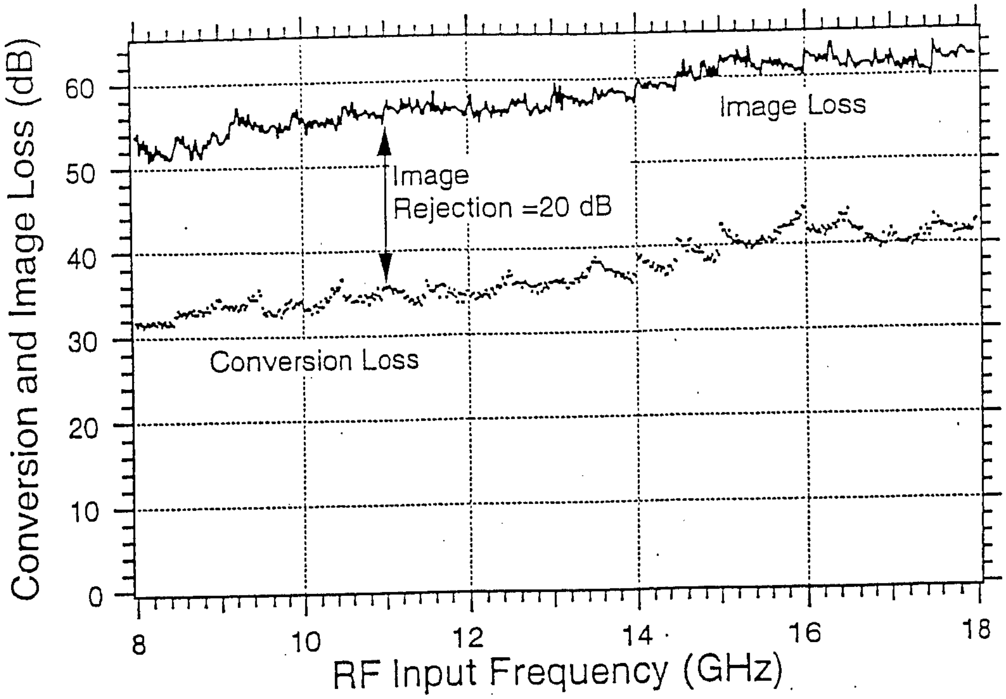

Figure 8

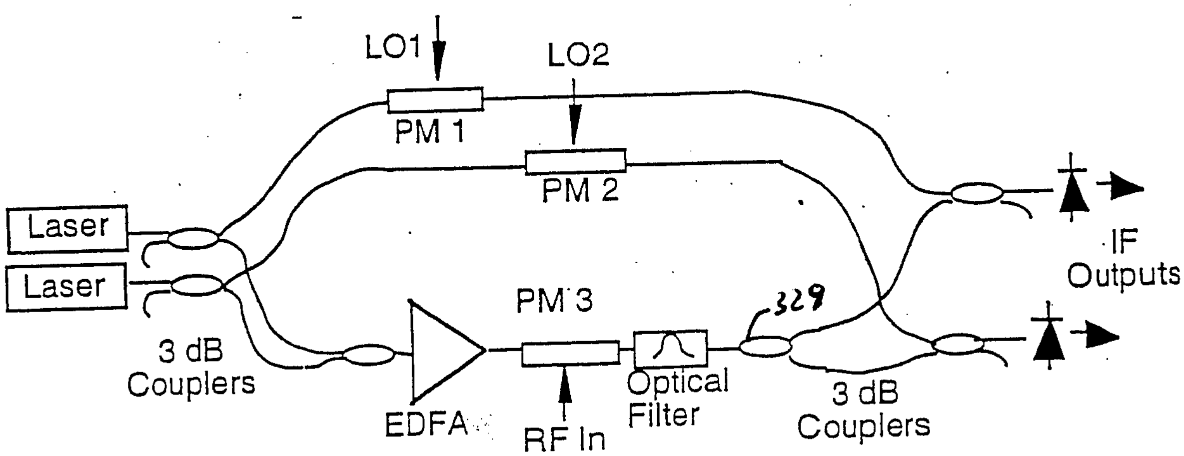

Figure 9